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GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA: COUNTRY UPDATE

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ABSTRACT

Ethiopia is located in the horn of Africa with a population of over 90 million. The economy is non oil driven and has grown in double digits during the last 10 consecutive years. The continuous economic growth has brought about a significant growth of energy demand including electricity. It is required to enhance the current installed electrical capacity of 2200 MW to 10,000 MW in a couple of years, to meet the electricity demand. The energy policy of the country allows developing electricity from all indigenous renewable energy resources including geothermal and private sector participations are encouraged to speed up the development process.

Ethiopia is endowed with high enthalpy geothermal resources, currently estimated to reach 10, 800 MW potential, distributed over 22 prospect areas. Since recent years a number of geothermal projects have been initiated and are being implemented, to advance geothermal development in the country. These include: (i) geothermal master plan study (ii) Aluto Langano geothermal expansion project, (iii) surface explorations at Tendaho, (iv) Tendaho shallow resources feasibility study, and (v) development of long term geothermal strategy.

According to the near future plan, a total of 675 MW geothermal power is to be developed from six selected prospects by 2020 and 2000 MW is expected by 2030. Both the private sector and public sector participation is envisaged to achieve this plan. Financial resources are secured or are on the process of being secured for the planned development under the public/private sector.

1. INTRODUCTION

1.1 Location and Economy

Ethiopia is located in the horn of Africa between 3.5° and 14°N and 33° and 48°E (Figure 1). The country has an area of 1.14 million km^2 and a population of over 90 million. The Ethiopian economy, which is non- oil-driven economy, has grown more than 11% for the last 10 consecutive years. In the existing Growth and Transformation Plan (GTP) which covers the year 2010/11-2014/15, the economy is expected to double with an expected yearly economic growth of a minimum 11 percent, including doubling the agricultural production of the country by the end of 2014/15 (Abayneh, 2013).

The GTP envisions a major leap in terms of not only economic structure and income levels but also the level of social indicators.

1.2 Energy and Electricity Sector

The energy sector in Ethiopia can be generally categorized in to two major components: (i) traditional (biomass), and (ii) modern (such as electricity and petroleum). As more than 80 % of the country's population is engaged in the small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of energy in the country.

FIGURE 1: Location map of Ethiopia and regional interconnection plan

The continuous economic growth has undoubtedly influenced the growth of energy demand. The current total installed electricity generation capacity has reached over 2,200 MW. The delivery of an adequate electricity service is essential, to fulfill the high growth rate of electricity demand which is currently 32% / yr. The generation capacity will increase to 10,000 MW at the end of Growth and Transformation Plan (2014/15). The aim is to address both domestic demands while exporting surplus power to neighboring countries and beyond. All the energy to be produced will focus in renewable energy resources to meet the planned climate resilient green economy of the country (EPA, 2011). The need to expand the transmission and distribution system is also emphasized in order to deliver the energy generated to the consumer in an efficient and reliable manner. The GTP further envisages increasing the customer base of the power utility from the current level of 2 million to 4 million and the universal electricity access rate from 45% to 75% (Abayneh, 2013).

The government policy direction is to generate virtually all of our electricity from clean and renewable sources centered on hydropower, with complementary geothermal, wind, solar and other renewable energy resources.

Hydropower generates more than 90% of electricity in Ethiopia. However, as the rainfall in Ethiopia varies considerably from year to year, the need to diversify the country's energy sources to ensure a stable supply is essential. It also implies that overdependence on hydropower makes energy supply unstable, resulting in heavy strains on the pace of growth in every sector and the whole economy by extension.

At the transmission front, the Ethiopia-Kenya, the proposed 500KV AC/600KV HVDC line between Ethiopia-Sudan and Egypt, and the proposed 230KV line between Ethiopia and Republic of South Sudan, are the major ones to be noted as their completion signifies the complete integration of Eastern Africa power market, taking into considerations the ongoing development of interconnection projects in the Nile equatorial lakes region, including the proposed 400kv line between Kenya and Tanzania (Figure 1). With the foreseen development of the Zambia-Tanzania-Kenya Interconnector, the efforts would contribute to the envisaged Inter-Africa Power Trade (Lemma, 2012).

1.2.1 Energy Policy

The government's Energy policy is an integral part of its overall development policy. It aims to facilitate the development of energy resources for economical supply to consumers. It seeks to achieve the accelerated development of indigenous energy resources and the promotion of private investment in the production and supply of energy. Electricity supply, as an element of the development infrastructure is being advanced in two fronts: (a) the building up of the grid based supply system to reach all administrative and market towns, and (b) rural electrification based on independent, privately owned supply systems in areas where the grid has not reached.

An independent power producer (IPP) may engage in power development for selling the generated electricity to the public utility, known as the single buyer model. The single buyer model does not exclude captive geothermal power generation, i.e. generation for own use in primary economic production or service industries owned by the developer. Engineering, procurement and construction (EPC) turnkey contracts could be negotiated and signed between private companies and the public utility, in which the private sector would have the role of not just as a project developer but also as a critical stakeholder that can bring financing to the table under the right circumstances.

2 GEOTHERMAL EXPLORATIONS AND DEVELOPMENT IN ETHIOPIA

2.1 Work Done in the Past

High enthalpy geothermal areas in Ethiopia are located within the Ethiopian Rift System (ERS). Tectonic and magmatic features show that the ERS to be a zone of particularly active continental crust thinning and opening. Due to a high volume of partial melts in an upwelling asthenosphere in ERS, the generation of primary and secondary magma is conducive to the occurrence of high enthalpy geothermal fluid circulation systems at economically accessible depth.

Ethiopia started long-term geothermal exploration in 1969. Over the years, an inventory has been built up of the possible resource areas within the Ethiopian sector of the ERS, as reflected in surface hydrothermal manifestations. The inventory work in the highland regions of the country is not complete but the rift system has been well covered. Of the about 120 localities within the rift system that are believed to have independent heating and circulation systems, about two dozen are judged to have potential for high enthalpy resources, for electricity generation (Figure 1). A much larger number are capable of being developed for non-electricity generation applications such as horticulture, animal breeding, aquaculture, agro-industry, health and recreation, mineral water bottling, mineral extraction, space cooling and heating, etc. (UNDP, 1973).

The early stages of geothermal explorations have identified sixteen areas to have geothermal resources suitable for electricity generation with a total potential of 5000 MW. Since the last two decades, geoscientific surveys mostly comprising geology, geochemistry, and geophysics, were carried out in a number of prospects (Teklemariam et al, 2005).

Exploration work peaked during the early to mid 1980's when exploration drilling was carried out at Alutu. Eight exploratory wells were drilled with five of these proving productive. Resource utilization was delayed until 1999. A 7.3 MWe net capacity pilot plant has been installed at Aluto since then. During 1993-98, exploration drilling has been carried out at Tendaho. Three deep and three shallow wells were drilled and geothermal fluids were encountered in the 200-600m-depth range.

The geothermal resources in Ethiopia are economically viable, due to the following main reasons:

- The resources have high reservoir temperatures ranging from over 200 to 335ºC;
- The depth to the reservoirs are economical, ranging from 500 to 2500 m;
- The resources have low non condensable gas content and low scaling potential; and
- The geographical location of the resources is very close to existing infrastructures (roads, transmission lines etc).

2.2 Work Done Recently

Since recent years a number of geothermal projects have been initiated and are being implemented, to advance geothermal development in the country. These include: (i) geothermal master plan study, (ii) Aluto Langano geothermal expansion project, (iii) surface explorations at Tendaho, (iv) Tendaho shallow resources feasibility study and (v) development of long term geothermal strategy.

2.2.1 Geothermal Master Plan Study

The project for formulating geothermal master plan in Ethiopia has started in 2013 with the technical assistance of the Japan International Cooperation Agency (JICA). The activities of the project include: (i) data collection and desk review (review of existing surface survey data, review of environmental issues, review of existing power system, remote sensing survey, identification of additional new field surveys and prioritization), (ii) nationwide survey (geochemical survey, geological survey, environmental and social impact survey), and (iii) data base and master plan development (data analysis, pre resource evaluation, database development, identifying MT survey targets, MT survey, identifying drilling targets in selected areas, database completion and master plan formulation.

The project is currently at its final stage and the following results have been obtained so far regarding high enthalpy geothermal prospect areas, geothermal potential and prioritization.

High enthalpy geothermal prospects in Ethiopia have been considered to be16 in number in the past. However recent desk studies and nationwide surveys have indicated that the number of prospects in the ERS to be 22 (Figure 2). The reasons for rise in the number of prospects are the discovery of new prospects and the consideration given to some of previously merged prospects to have more than one independent system. Some of the newly discovered prospects are located off the Rift axis as opposed to previous assumptions of all high enthalpy resources are located along the rift axis.

The geothermal electrical potential of the resources in the country has been estimated using volumetric method and Monte Carlo probabilistic assessment. This methodology is considered to be better suitable to apply in geothermal prospects of Ethiopia, where most of the prospects are at an initial stage and the details of the geothermal reservoir are not yet known. In this methodology, volume and average temperature are inferred. The maximum depth shall be the depth economically reachable and a liquid dominated geothermal reservoir is considered. Accordingly calculations have given a minimum potential of 2100 MW, a most probable potential of 4200 MW and a

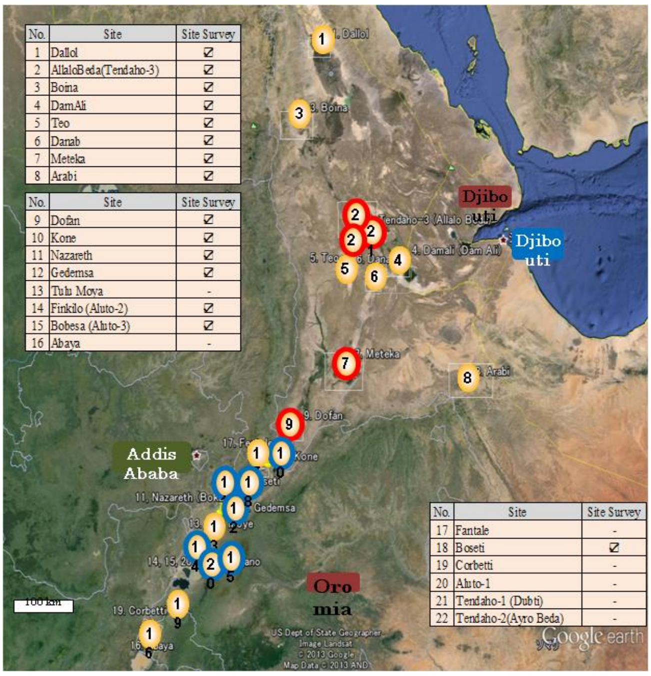

FIGURE 2: Location map of geothermal prospects

maximum potential of 10, 800 MW (JICA study team, 2014).

The geothermal prospects were also prioritized based on: (i) development status, (ii)) environmental and social impact, and (iii) economics. Accordingly Aluto Langano and Tendaho prospects are given the highest priority.

2.2.2 Aluto Langano Geothermal Expansion Project

Ethiopia and Japan conducted a feasibility study in 2010 for the expansion and development of the Aluto Langano geothermal field and the expansion plan has been proved to be feasible. A project for resource evaluation by drilling of three appraisal deep wells and one reinjection well has been designed with investment cost of about 30 Million US$ (West Jec, 2010). The project is financed by the government of Ethiopia, Japanese government and the World Bank. In this project, so far the following activities have being carried out: (i) Pre drilling preparation including well pad preparations, maintenance, testing and erection of an existing rig at the project site, and (ii) purchase of drilling consumables from overseas and capacity building required for the project. The drilling of the first well has commenced in October 2013. Additional work to be conducted in parallel with the drilling has commenced, with the assistance of Icelandic international development agency (ICEIDA) and the World Bank, which includes, production wells drilling, site selection and purchase of rigs and additional consumables. The ultimate goal of the expansion plan is to install 2 x 35 MW units in two phases.

2.2.3 Surface Explorations at Tendaho

On the bases of previous surveys, three deep wells and three shallow wells have been drilled in Tendaho area. Two of the three deep exploration wells, drilled in the northwestern part of Tendaho graben were drilled in this part of Dubti farm. The Stratoid series basalt layer was penetrated but, while a temperature of more than 270 ^{O}C was measured, no geothermal fluid inflow into the wells occurred (EIGS and Aquater, 1996). The rock unit in its drilled areas was not as fractured as expected and permeability was low. During drilling, a zone of geothermal water inflow had been crossed above the 500m depth range and it was later drilled into by three shallow wells. A reservoir at a temperature of 236-253^{O}C was confirmed to exist in the 200-500 m depth range.

In 2013/2014 surface exploration for the purpose of siting additional deep exploratory wells has been conducted with the assistance of the African Rift Geothermal Facility (ARGeo). This exploration program included, review of previous data, new data generation in MT, soil geochemistry and geology and integration of all data to come up with a better conceptual modeling of the deep geothermal system.

Under ARGeo, geologic and geophysical data and interpreted geo-referenced images were imported to Leapfrog geothermal software, and integrated to develop a conceptual model. The main product of this study is a 3D model (Figure 3). In this Figure a 3D slice of Dubti area of interest is shown with 2 example deep wells, viewed from the east. The darker orange volume is considered most prospective (higher probability of successful wells). Accordingly from the investigated area, it was recommended that Dubti be given first priority for continued exploration (Stimac, et al, 2014).

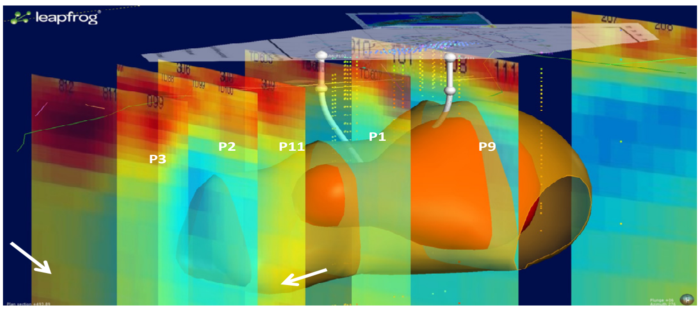

FIGURE 3: 3D slice of Dubti area of interest, with 2 example deep wells

2.2.4 Tendaho Shallow Resources Feasibility Study

In 2013/2014 the feasibility of utilizing the previously discovered shallow reservoir at Tendaho has been conducted with the assistance of French development agency (AFD). The results obtained with 10,000 Monte Carlo trials is presented in graphical form in Figure 4, where the most frequent power plant value is 9.6 MWe, while the values corresponding to 90, 50 and 10% probability are 7.4, 9.7, and 13 MWe. On the basis of these considerations, a power plant capacity in the order of 7 to 10 MWe can be considered the most probable for the shallow reservoir.

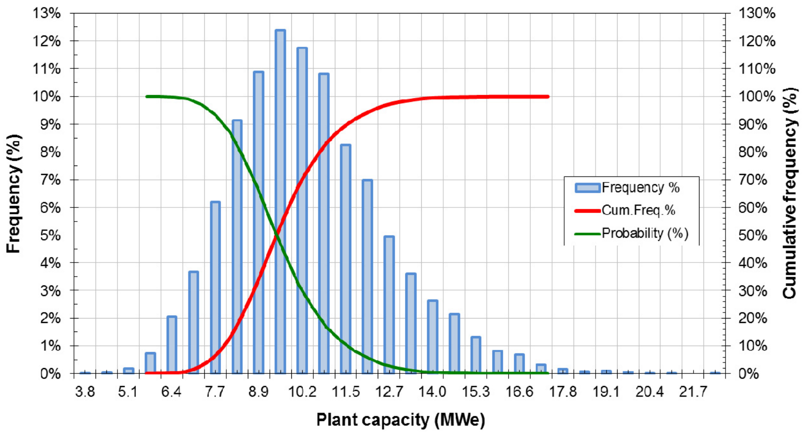

FIGURE 4: Probability distribution of the power capacity of the shallow reservoir

The total capital expenditure to develop the resource to 12 MW has been calculated to be about 32 Million US$. The financial analysis for cost of electricity under public ownership without considering exploration cost and taxes indicated a value of 3.5 US cents/ kWh. Technical, economical and environmental evaluations concluded that the proposed project is feasible.

2.2.5 Development of Long Term Geothermal Strategy

The project is being implemented with financial assistance from scaling up renewable energy program (SREP). The key components of this work include: 1) generating an overview of Ethiopia's geothermal sector as currently stands, including key actors and their roles, and pertinent legal and regulatory frameworks; 2) performing a detailed assessment of international approaches to development of the geothermal value chain with a specific focus on effective management of upstream risks as well as on successful models for private sector involvement; 3) working closely with the Ministry of Water and Energy, Geological Survey of Ethiopia and other relevant entities, to review their current portfolio of priority projects and define associated financing needs; completion of underlying analytics to help vet identified projects may also be required; 4) assessing portfolio development options with a particular emphasis on advantages and disadvantages of alternative models for stakeholders in both the public and private sectors, as well as estimating investment requirements and economic benefits from alternatives; 5) identifying at a high-level organizational capacity requirements, support needed by private sector firms and potential gaps in/modifications needed to the regulatory/legal framework in order for the recommendations to be rolled-out; and 7) creating an action plan for strategy adoption and subsequent delivery by relevant institutions in the country (MoW&E., 2012).

2.3 Near Future Plan

According to the near future plan, a total of 675 MW geothermal power is to be developed from six selected prospects by 2020 and 2000 MW by 2030 (GSE et al, 2008). Both the private sector and public sector participation is expected to achieve this plan.

Regarding the private sector participation, surface exploration conducted by a private company called Reykavik Geothermal (RG) has indicated a geothermal potential of up to 1000 MW at Corbeti geothermal prospect (RG, 2012). Heads of terms of power purchase agreement for Corbetti geothermal development has been signed in October, 2013 between Ethiopian Electric Power Corporation (EEPCo) and RG. The agreement considers development of the Corbeti prospect to 1000 MWe in the next 8-10 years, with estimated investment cost of 4 billion US$. Currently mobilization works are being conducted by RG to commence test drillings.

The following financial resources are secured or are on the process of being secured under the public sector: (i) for the expansion of the Aluto Langano Geothermal field to 75MW, a 24.5 million US$ has been secured for the planned production drilling, from SREP. Furthermore, finance for the planned expansion power plant is being looked for from the Japanese government and the World Bank, and (ii) The development of the Tendaho geothermal resources at various sites within Tendaho, is scheduled with financing of the French Development Agency, ARGeo, Geothermal Risk Mitigation Facility (GRMF) of the Africa Union, the World Bank and Ethio-Iceland bilateral cooperation.

4. CONCLUSIONS

The intensity of geothermal exploration activities in Ethiopia has increased since the last few years. Additional data base is being created and new discoveries are being achieved. Currently, geothermal : (i) is integrated in the national energy development plan, (ii) has growing participation of international financial institutions, bilateral donors and development agencies, and (iii) has increased private sector participation in development projects.

Despite these efforts, high upfront capital costs of geothermal projects, risks associated with the exploration phase; and limitations in local technological and human resource capacity, remain challenging to speed up the development as required.

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